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RESEARCH MEMORANDUM

HYDRODYNAMIC CHARACTERISTICS OF AERODYNAMICALLY REFINED PLANING-TAIL HULLS

By

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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

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HYDRODYNAMIC CHARACTERISTICS OF AERODYNAMICALLY REFINED PLANING-TAIL HULLS

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SUMMARY

Investigations were made in order to determine the hydrodynamic characteristics of two aerodynamically refined planing-tail hulls. One hull had an afterbody that was a tapered boom and the other had two afterbodies consisting of tapered booms fairing out of the engine nacelles. Over a wide range of center-of-gravity location, both models had a large range of elevator deflection for stable take-offs. The lower trim limit of stability peak was high for both configurations but trims obtainable were great enough to permit operation above the lower trim limit. No upper-limit porpoising was encountered with either configuration. Stable landings could be made over a wide range of trim and location of the center of gravity, provided the vertical chine strips were not extended to the point of the step. Extension of the vertical chine strips to the point of the step resulted in unstable landings. The relatively high trims and the vertical chine strips were effective in reducing the propeller spray. The hump load-resistance ratios for the aerodynamically refined hulls were low (2.9 to 3.6). Directional instability was noticed over a short range of speed with the single-boom configuration. The twin booms provide a substantial amount of transverse righting moment.

INTRODUCTION

In order to obtain flying-boat forms that will permit increased range and speed over those in present-day use, several refinements of the planing-tail type of hull have been investigated in the Langley 300 MPH 7- by 10-foot tunnel and in Langley tank no. 2. The air drag of the planing-tail flying-boat hull employing a deep step and full-step fairing has been shown in reference 1 to be considerably less than that of a comparable conventional-type hull. In reference 2, the hydrodynamic characteristics of this planing-tail-hull configuration were shown to be an improvement over those of a conventional hull. The aerodynamic characteristics of several modifications of the planing-tail type of hull embodying an airfoil-section forebody plan form and slender "boom like" afterbodies have been reported in reference 3. This aerodynamic refinement resulted in a decrease in hull volume and a substantial decrease in the aerodynamic drag below that of the hulls reported in reference 1. The two configurations, which had lower drag than the others, were a configuration with an "afterbody" that was simply a tapered boom of circular cross section (see fig. 1(a)) and a configuration that had two "afterbodies" consisting of tapered booms fairing out of the engine nacelles (see fig. 1(b)).

The results of the hydrodynamic investigation of these two configurations conducted in Langley tank no. 2 are given in the present paper. Because of the large portion of the total volume forward of the center of gravity, the problem of airplane balance may limit the application of these hulls to special-purpose, high-performance airplanes.

There was some doubt that a small conical boom would be a hydrodynamically adequate substitute for an afterbody, although tests of reference 4 had indicated that a small cylindrical boom might be sufficient. Consequently, there was included in the wind-tunnel investigation a hull in which a small tail float was faired into the end of the tail boom (see fig. 1(c)). Exploratory tank tests were made with the tail float on the single-boom configuration but these tests showed that the tail float actually impaired take-off performance and tank tests were discontinued in favor of the simpler hulls having lower drag.

SYMBOLS

C_{Δ_o}	gross load coefficient $\left(\Delta_o/wb^3\right)$
C_Δ	load coefficient $\left(\Delta/wb^3\right)$
C_V	speed coefficient $(V/\sqrt{gb})$
C_R	resistance coefficient $\left(R/wb^3\right)$
Δ/R	load-resistance ratio
Δ_o	gross load on water, pounds
Δ	load on water, pounds
R	resistance, pounds
V	speed, feet per second
τ	trim, measured between forebody keel and horizontal, degrees
g	acceleration of gravity, feet per second per second

b maximum beam of hull (6.43 ft, full size)

w specific weight of water (63.0 lb/cu ft in these tests)

$\bar{c}$ mean aerodynamic chord

DESCRIPTION OF MODELS

The model having an afterbody consisting of a single boom was designated Langley tank model 237-7B. Photographs of this model are shown in figures 2(a) and 2(b). The general arrangement and hull lines are shown in figures 3 and 4, respectively. The model with the twin booms was designated Langley tank model 237-7TB. Photographs of this model are shown in figures 5(a) and 5(b). General arrangement and hull lines are shown in figures 6 and 7, respectively. Offsets for both configurations are given in reference 3.

The forebody plan form was a modified 16-series symmetrical airfoil section with length-beam ratio of 7.0. The upper portion of the hull as used in the wind tunnel was not reproduced. In order to provide adequate spray control, chine strips of 0.05b depth were used on both configurations. On the single-boom configuration, the chine strips extended from 0.5b aft of the nose to the point of the step where they were faired to zero depth. The chine strips on the twin-boom configuration extended from 0.5b aft of the nose to 1.45b forward of the point of the step. The booms of either configuration were simple cones of circular cross section. The twin-boom configuration had two conical booms, one faired out of each engine nacelle. The nacelles of this configuration were moved outboard to reduce the interference between the forebody wake and the booms. Both configurations had slightly shorter booms than those tested in the wind tunnel, but it is believed this difference would have no appreciable effect on the aerodynamic characteristics.

These models were $\frac{1}{16}$-size powered dynamic models of a hypothetical flying boat of 65,000 pounds gross load $\left(C_{\Delta_0} = 3.87\right)$. The wing and power used for both configurations corresponded to those of the Boeing XPBB-1 which resulted in a wing loading of 35.6 pounds per square foot and a power loading of 14.8 pounds per brake horsepower for the hypothetical design. The wing was located as shown in figures 3 and 6. The wing incidence relative to the base line was 4°. The tail surfaces of the single-boom configuration were those of the Boeing XPBB-1 to $\frac{1}{16}$ scale. The area of the horizontal tail surfaces of the twin-boom configuration was the same as that of the single boom, but the shape and arrangement were altered to facilitate mounting between the vertical fins. The total area of the vertical fins was approximately 1.75 times that used on the single-boom model.

PROCEDURE

Take-off Stability

The center-of-gravity limits of stability were determined by making accelerated runs at a constant acceleration of one foot per second per second to take-off, with fixed elevators and full power. A sufficient number of center-of-gravity locations and elevator settings were tested to define the stability limits. A center-of-gravity limit of stability is defined as that condition at which the amplitude of trim oscillation reaches a value of 2° or the trims at high speeds become less than 2°. Trims of less than 2° at high speeds were considered to be unsafe for practical operation. The variation of trim with speed was also observed during these runs. To find the trim limits of stability, the towing carriage was held at constant speeds, while the model trim was slowly increased or decreased until the porpoising limit was crossed.

Landing Stability

Prior to landing, the model was trimmed in the air to the desired contact trim with the carriage held at a constant speed slightly greater than the model flying speed. The carriage was then decelerated at a constant rate of three feet per second per second allowing the model to glide onto the water with fixed elevators in simulation of an actual landing. The descent to the water from flight was made from a height of 0.3b above the water. This procedure was used to hold the sinking speeds to reasonable values (approx. 300 ft/min full size). After the first contact the rise restriction was removed. Landings were made with the center of gravity located at $0.20\bar{c}$, $0.30\bar{c}$, and $0.40\bar{c}$, using one-quarter static thrust.

Spray

The range of speeds over which spray was in the propellers was defined for a series of gross loads. (See reference 5.) The model was free to trim about the $0.30\bar{c}$ location of the center of gravity with the elevators fixed at 0°. Constant-speed runs were made at full power starting with a light load on the water and increasing the load until spray entered the propellers.

Resistance

The resistance characteristics were obtained with the wing and tail surfaces removed. The tail booms of both configurations were supported by auxiliary means. A lift curve was determined from the variation in take-off speed with trim observed in the take-off stability tests. The load on the water corresponding to this curve was applied by dead weights. The range of trim tested at any speed was selected from the stability tests as being the range of stable trim obtainable at that speed by the use of the elevators. The resistance selected at each speed was the lowest resistance obtained at that speed. The trims at high speed were arbitrarily limited to 12°.

Static Transverse Stability

The static transverse stability was determined by inclining the model with the wing removed. The model was balanced at its normal gross load with weights located on the center line at the 0.30$\bar{c}$ location of the center of gravity and then moved outboard to apply an upsetting moment. The resultant angle of heel was measured as the angle between the plane of symmetry and the vertical.

RESULTS AND DISCUSSION

The exploratory tests made with a tail float (see fig. 1(c)) indicated that such a configuration operated in a range of trim which was lower than that obtained with the boom alone. Near the take-off speed the model trimmed up suddenly resulting in premature take-offs. Because the tail float was apparently clear at the start of the motion, this trimming up was thought to be the result of negative air pressures acting on the float bottom as it operated in the trough of water formed in the forebody wake. This hydrodynamic feature, coupled with the increase in air drag due to the float, caused interest to be centered on the hull with the boom alone.

Take-Off Stability and Trim

The center-of-gravity limits of stability for the two models are given in figure 8 as a plot of elevator deflections against center-of-gravity locations. The range of fixed elevator deflection for stable take-offs was large for both configurations. For the single-boom configuration, this range increased from 15° at 0.20$\bar{c}$ to 30° at 0.40$\bar{c}$. The range of fixed elevator deflection for the twin-boom configuration was about 25° at 0.20$\bar{c}$ and 40° at 0.40$\bar{c}$. At the maximum fixed elevator deflection of −30° take-offs of both configurations were stable.

The region of lower-limit porpoising encountered with the lower elevator deflections is shown in figure 9 where the trim limits of stability for the two models are plotted against speed coefficient. The lower trim limits were the same for both configurations with the exception of a slight difference in the minimum speed at which lower-limit porpoising was first encountered. The maximum trim at which lower-limit porpoising appeared was high for both configurations. No upper-limit porpoising was encountered with either configuration. This absence of upper-limit porpoising enabled stable take-offs to be made with full elevator deflection (-30°) as shown in figure 8. The high peak trims and the absence of upper-limit porpoising were probably both due to the high sternpost angles $\left(15\frac{1}{2}^{\circ}\right)$.

In figure 10, typical plots of variation in trim of the two configurations at fixed elevator deflections are plotted against speed coefficient for the three locations of the center of gravity investigated. Typical photographs are shown in figures 11 and 12. The static trims of both configurations were high (approx. 10°). The trim of the single-boom configuration increased until a speed coefficient of approximately 2.5 was reached. From this speed, until a speed coefficient of approximately 5.0, the trim remained fairly constant at large elevator deflections (-15° to -30°). This flattening of the trim track was the result of the powerful forebody roach which rose almost vertically and impinged on the boom in this speed range. The twin-boom configuration had higher hump trims since the forebody roach did not strike the booms. With both models, trims obtainable with a wide range of elevator deflection were high enough to permit operation above the lower trim limit of stability and no upper-limit porpoising was encountered.

The stability and trim characteristics of the two configurations differ chiefly in their range of elevator deflection for stable take-offs and the operating trims for given elevator deflections. These differences in stability and trim characteristics for the two models may be attributed primarily to differences in the tail surfaces, differences in the chine strips, and the change in position of booms relative to the roach behind the forebody. Of these three changes, the last constitutes the only difference that is inherent in the change from single-boom to twin-boom configuration. The significant conclusion appears to be that both the single-boom and twin-boom configurations can be designed to have a large range of fixed elevator deflection for stable take-offs over a wide range of location of the center of gravity.

Landing Stability

The maximum amplitudes of oscillation in trim and rise during landing of the twin-boom configuration are shown in figure 13. Landings were stable at all contact trims and positions of the center of gravity.

The maximum amplitudes of oscillation in trim and rise during landings of the single-boom configuration are shown in figure 14. At forward positions of the center of gravity, violent lower-limit porpoising occurred during the landing runout for all landing trims. At after positions of the center of gravity lower-limit porpoising occurred at landing trims below 7°. This instability could not be associated with the boom inasmuch as this portion of the hull was generally clear of the water when porpoising occurred. The presence of the vertical chine strips near the point of the step appeared to introduce an undesirable bow-down hydrodynamic moment which resulted in low trims. Extending the chine strips aft on the twin-boom configuration caused similar landing behavior for this model.

Satisfactory landing stability, therefore, can be attained with either configuration. To avoid instability during the landing runout, however, vertical chine strips near the point of the step should be avoided.

Spray

The range of speed over which spray entered the propellers is plotted against gross load coefficient in figure 15 for both configurations. At the gross load used for the stability tests (65,000 lb, full size, C_{Δ_0} of 3.87), the propellers of the twin-boom configuration operated in spray over a shorter speed-coefficient range (C_V = 2.0 to 2.6) than did those of the single-boom configuration (C_V = 1.4 to 3.8) as a result of the higher trims and greater nacelle spacing of the twin-boom model. For both models the chine strips produced a confused pattern of light spray which tended to become more intense as load was increased beyond the load at which spray first entered the propellers. At the gross load used for stability tests the propeller spray of both models was satisfactory. Figures 11(b), 11(c), and 12(a) are photographs of the models operating in the spray region at normal gross load of 65,000 pounds, full size.

At high trims, through a speed range from approximately C_V = 6 to take-off, transverse spray from the forebody, aft of the vertical chine strips, wetted the under surface of the wing and the booms of the twin-boom configuration.

Resistance

Resistance coefficient, load-resistance ratio, trim, and load coefficient at best trim (with 12° considered the maximum usable trim at high speed) are plotted against speed coefficient in figure 16. The hump Δ/R values of 3.6 for the single-boom and 2.9 for the twin-boom are considerably less than those obtained in well-designed conventional hulls but are of the same order as those of single-float seaplanes. Actually a lower power loading than was used in the powered model tests would be needed in order to take off without assistance; a high-speed airplane would have such a low power loading. High hump trims and, therefore, high hump resistance were natural results of placing small booms high with respect to the forebody.

The twin-boom model appeared to have inherently higher resistance than the single-boom model over most of the speed range. At the hump speed the single boom rode on the roach behind the forebody. The resultant decrease in trim tended to lower resistance. At high speed, the differences in the resistance of the two models may be attributed to three factors: first, the difference in air drag as a result of the methods used to connect the hydrodynamic components; second, the differences in the vertical chine strip configuration; and third, the differences in spray on the tail booms. It is difficult to find a practical location for the twin booms that would permit them to be clear of spray at high speeds.

Directional Stability

No quantitative study was made of directional stability. The models, however, were attached to a tubular staff which was slightly flexible torsionally and a decided tendency to yaw was noticed at a speed coefficient of about 4.0 on the single-boom model. This tendency occurred over a speed-coefficient range of less than 0.3. In this region the peak of the roach from the forebody was in contact with the end of the boom. The twin-boom configuration showed no tendency to yaw since the forebody roach did not strike the tail booms.

Static Transverse Stability

The transverse righting moment of the twin-boom configuration (full size) without tip floats is plotted against angle of heel in figure 17. The righting moment required for this hull as determined by the U. S. Navy specification SR-59C (reference 6) at an assumed angle of heel of 6° (considered to be representative of the angles for submergence of wing-tip floats) is also shown. The twin booms provided a substantial amount of the transverse righting moment required.

CONCLUSIONS

The results of the tests to determine the hydrodynamic characteristics of aerodynamically refined planing-tail seaplane hulls, having slender boom-like afterbodies, indicate the following conclusions:

1. Both the single-boom and twin-boom configurations had a large range of fixed elevator deflection for stable take-offs over a wide range of location of the center of gravity.

2. The peaks of the lower trim limits of stability were high (11.3° for the single-boom configuration and 11° for the twin-boom configuration). However, trims obtainable were great enough to permit operating above the lower trim limits and no upper trim limits of stability were found.

3. Adequate landing stability can be obtained over a wide range of contact trim and center-of-gravity position provided the vertical chine

strips are not extended to the point of the step. Extension of the vertical chine strips to the point of the step resulted in unstable landings.

4. The vertical chine strips and the relatively high operating trims resulted in light propeller spray.

5. The hump load-resistance ratios for both configurations (3.6 for the single-boom model and 2.9 for the twin-boom model) were lower than those for conventional hulls.

6. Directional instability was noticed over a short speed range with the single-boom configuration.

7. The twin booms provide a substantial amount of transverse righting moment.

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REFERENCES

1. Riebe, John M., and Naeseth, Rodger L.: Aerodynamic Characteristics of Three Deep-Step Planing-Tail Flying-Boat Hulls. NACA RM No. L8I27, 1948.

2. Suydam, Henry B.: Hydrodynamic Characteristics of a Low-Drag, Planing-Tail Flying-Boat Hull. NACA RM No. L7I10, 1948.

3. Riebe, John M., and Naeseth, Rodger L.: Aerodynamic Characteristics of a Refined Deep-Step Planing-Tail Flying-Boat Hull with Various Forebody and Afterbody Shapes. NACA RM No. L8F01, 1948.

4. Wadlin, Kenneth L.: Preliminary Tank Experiments with a Hydrofoil on a Planing-Tail Seaplane Hull. NACA RB No. L4C28, 1944.

5. Dawson, John R., and Walter, Robert C.: The Effects of Various Parameters on the Load at Which Spray Enters the Propellers of a Flying Boat. NACA TN No. 1056, 1946.

6. Anon.: Specification for Transverse Stability of Seaplanes. Displacement and Location of Auxiliary Floats. NAVAER SR-59C (superseding SR-59B), Bur. Aero., Feb. 20, 1942.

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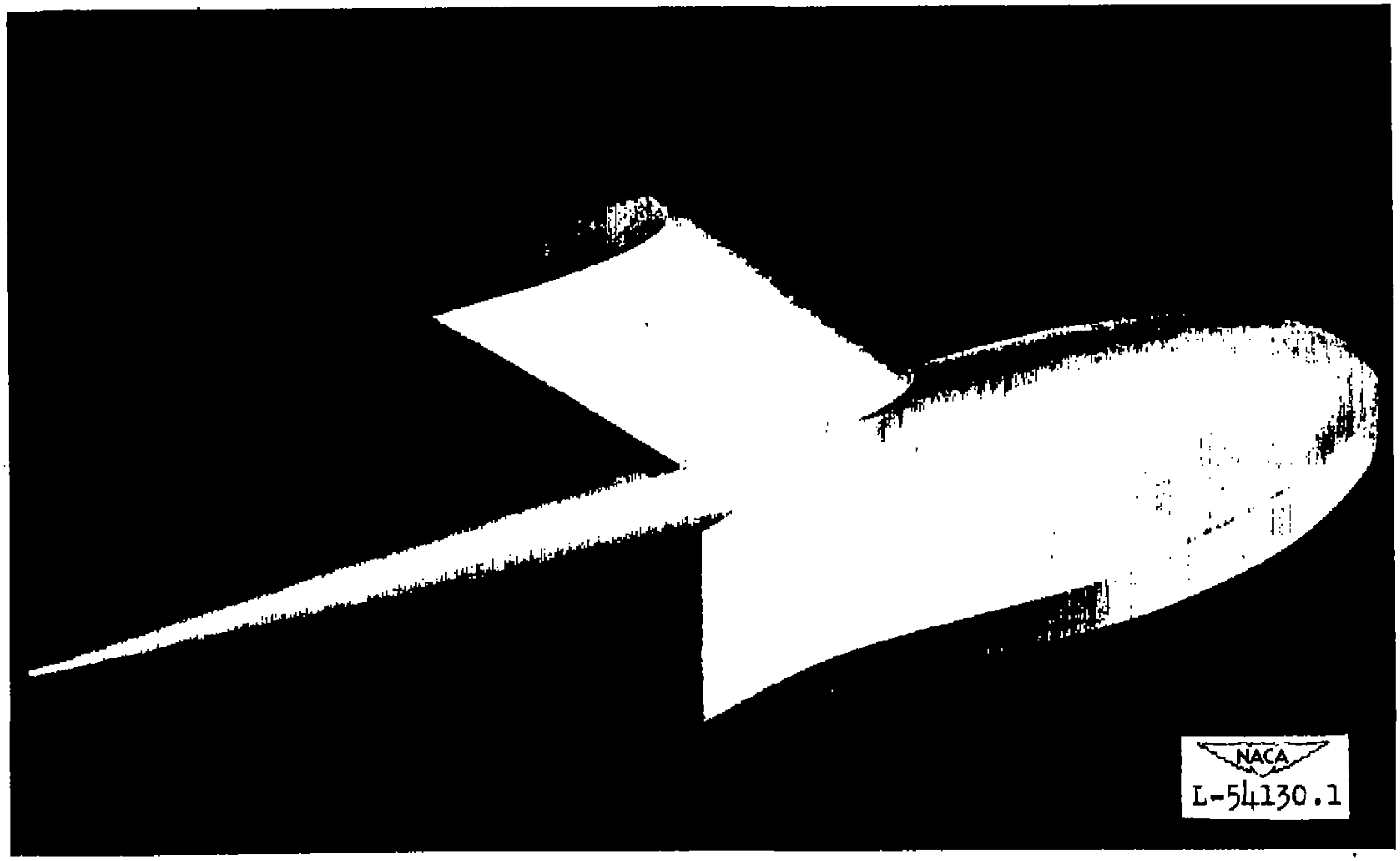

(a) With single boom. (Langley tank model 237-7B.)

Figure 1.- Wind-tunnel models.

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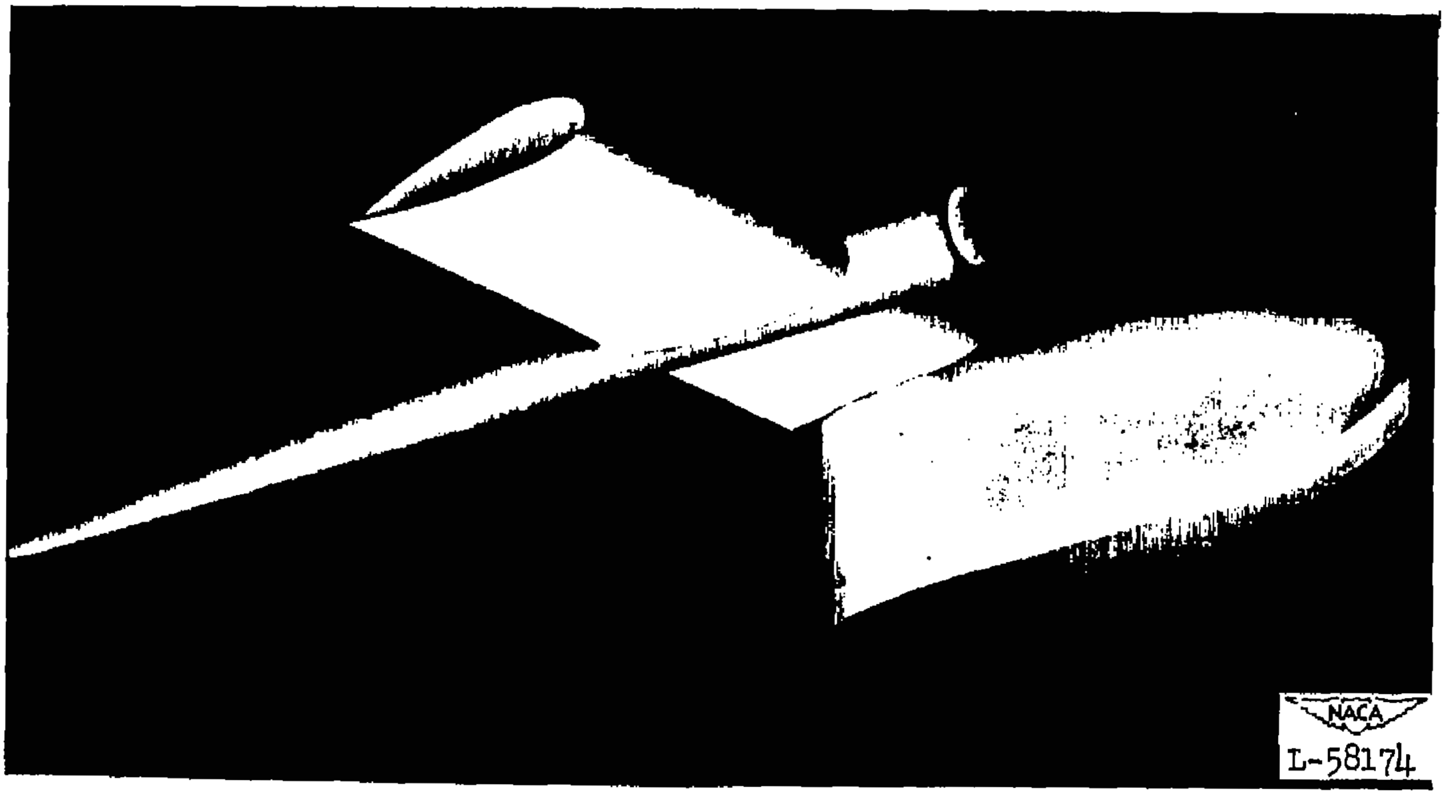

(b) With twin booms. (Langley tank model 237-7TB.)

Figure 1.- Continued.

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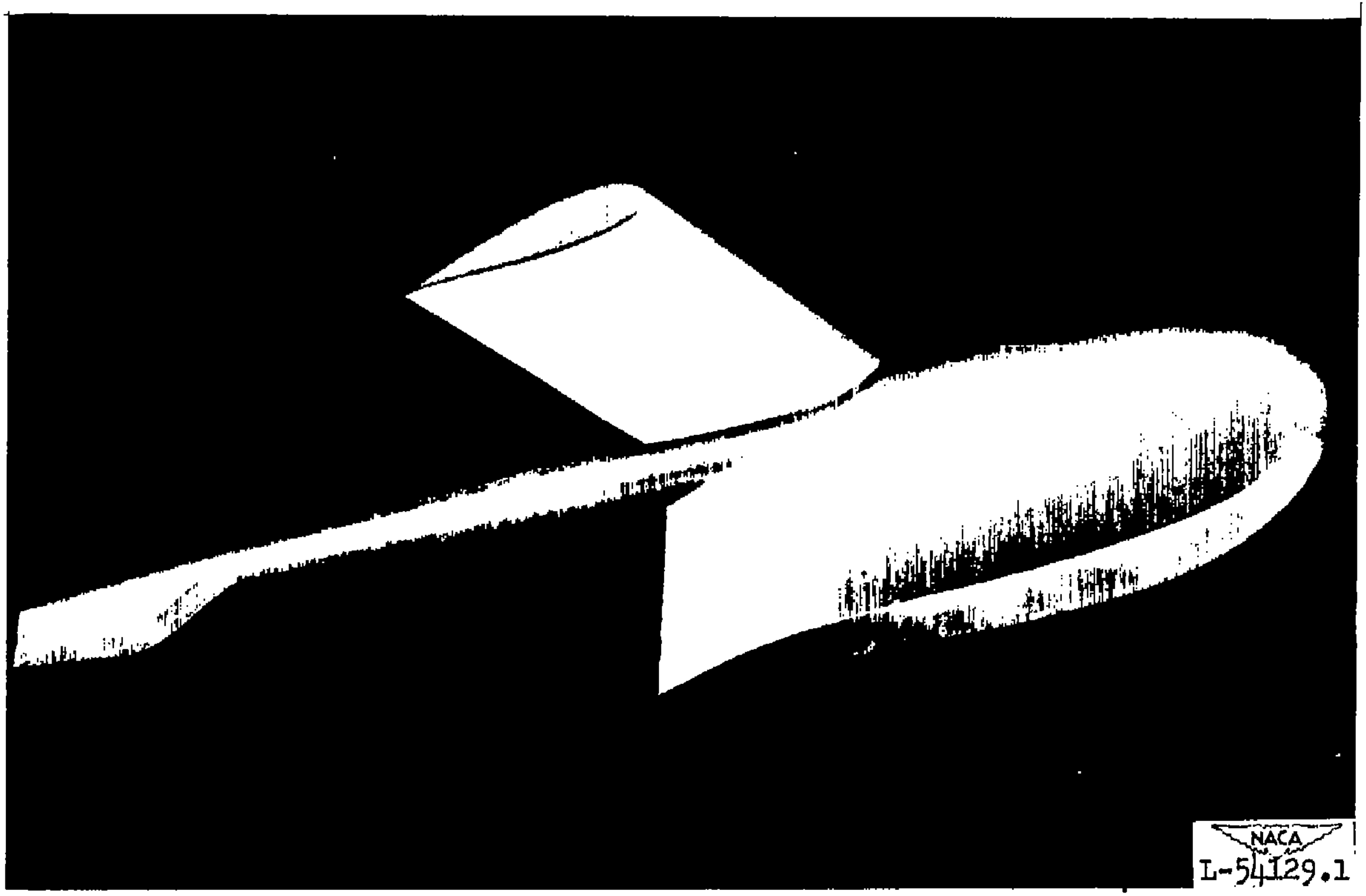

(c) With single boom and tail float. (Langley tank model 237-7F1.)

Figure 1.– Concluded.

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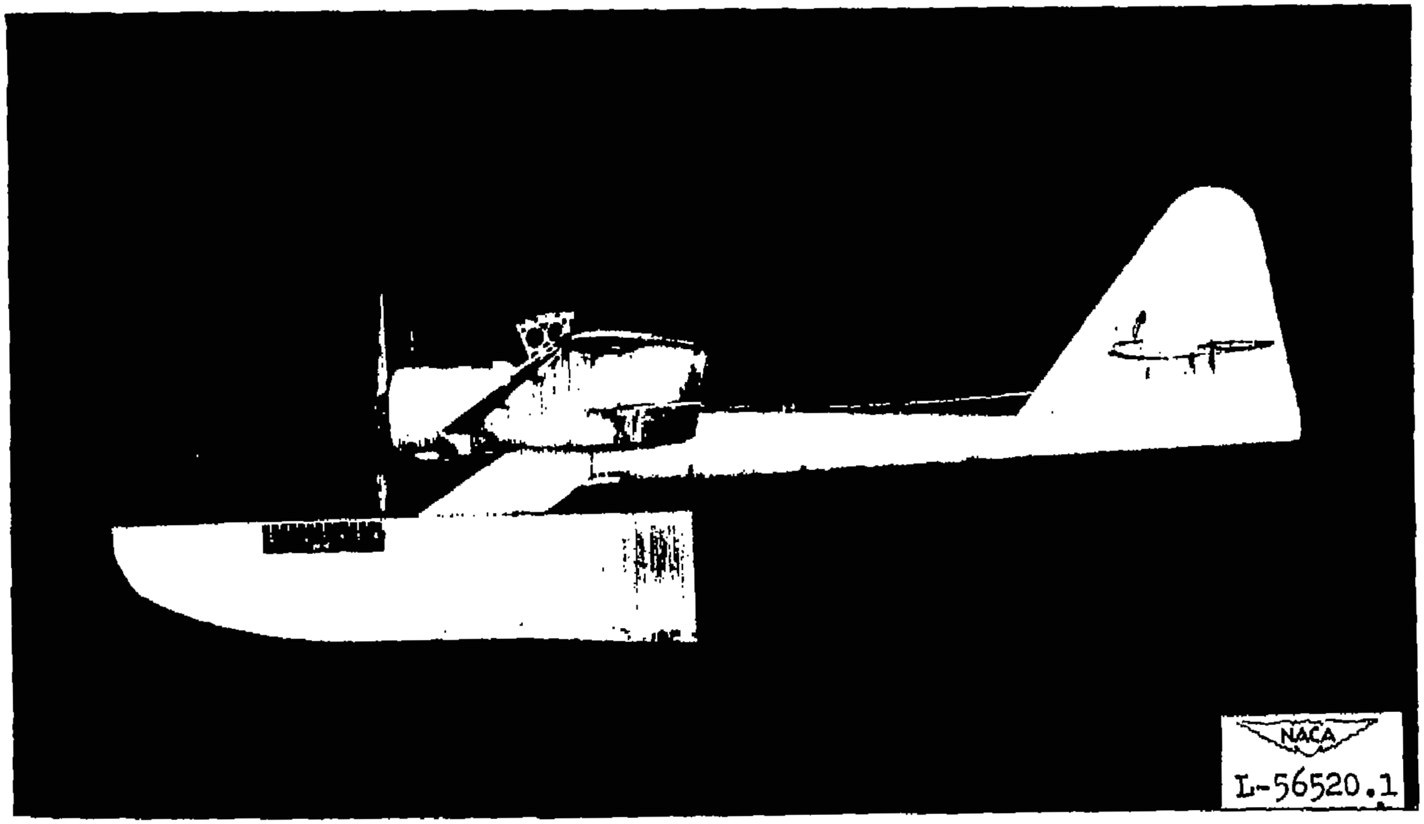

(a) Profile view.

Figure 2.- Model with single boom. Langley tank model 237-7B.

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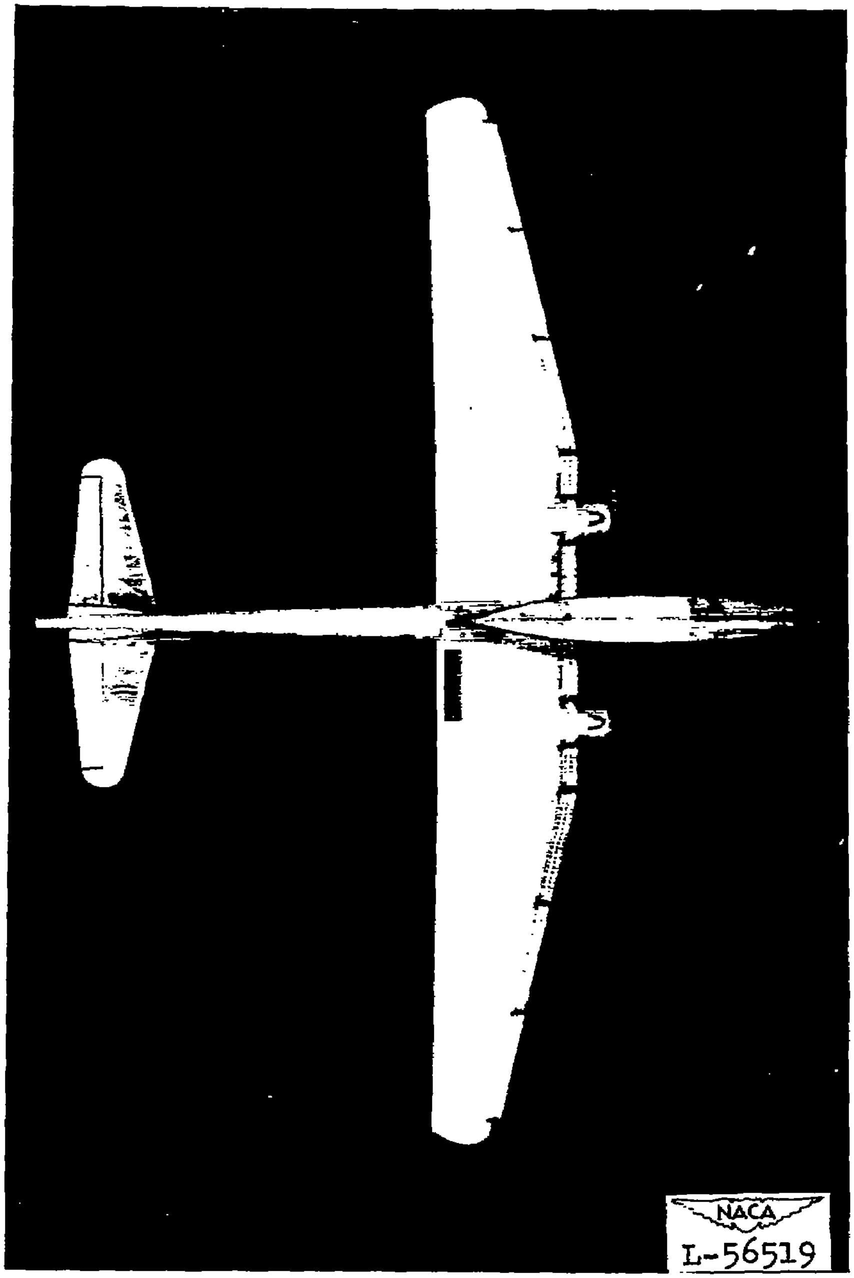

(b) Bottom view.

Figure 2.- Concluded.

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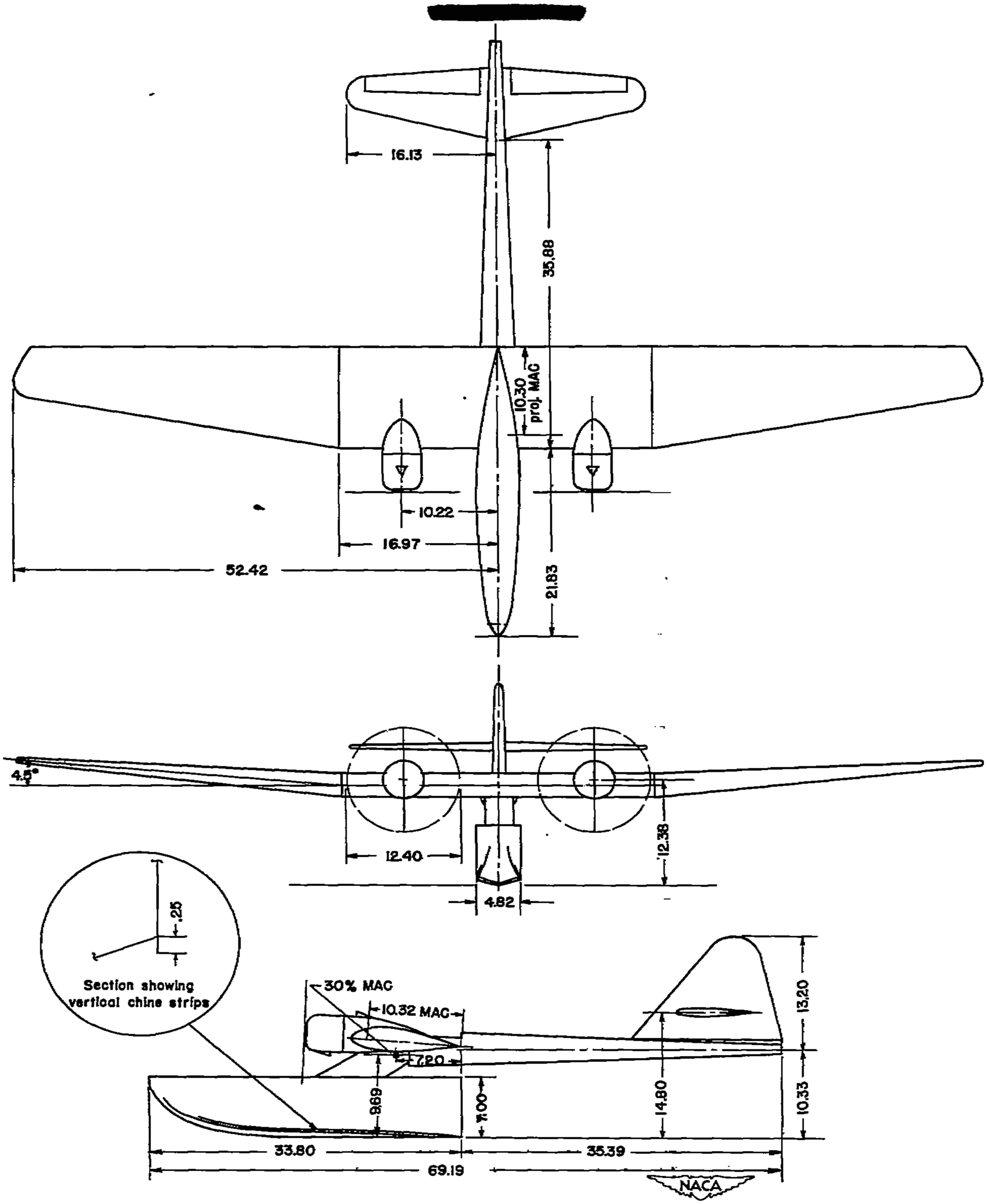

Figure 3.– General arrangement of model 237-7B. (All dimensions are in inches.)

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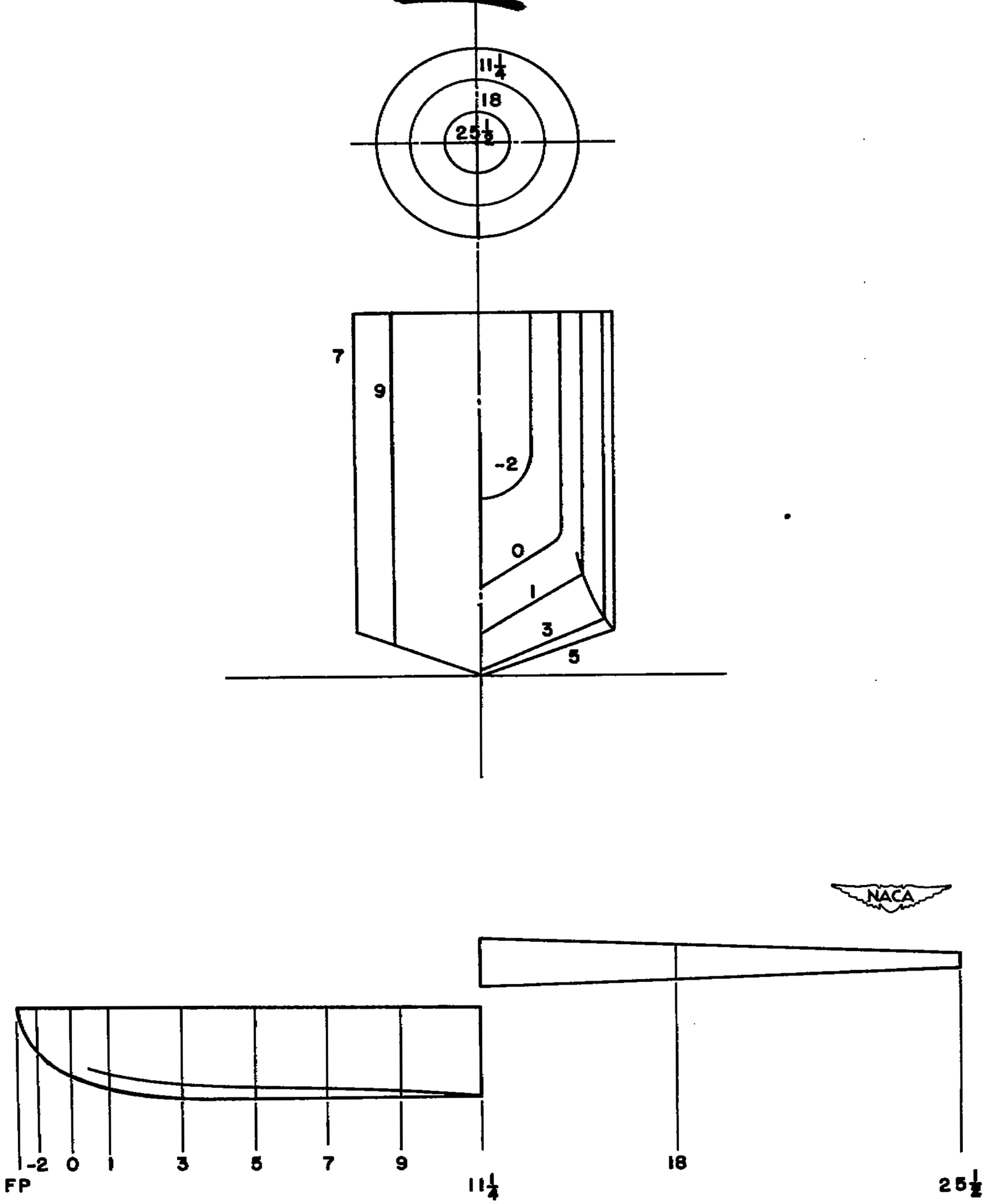

Figure 4.– Hull lines of model 237–7B.

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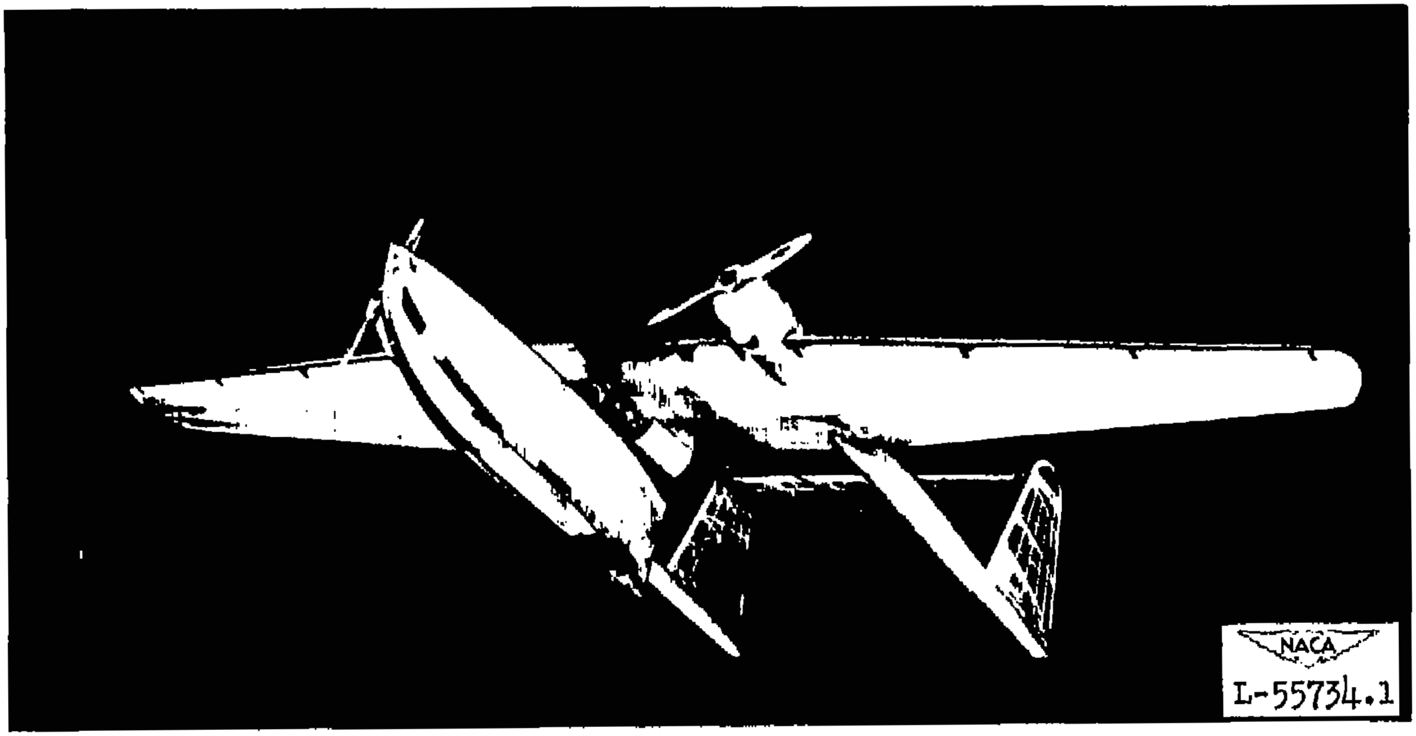

(a) Three-quarter bottom view.

Figure 5.– Model with twin booms. Langley tank model 237-7TB.

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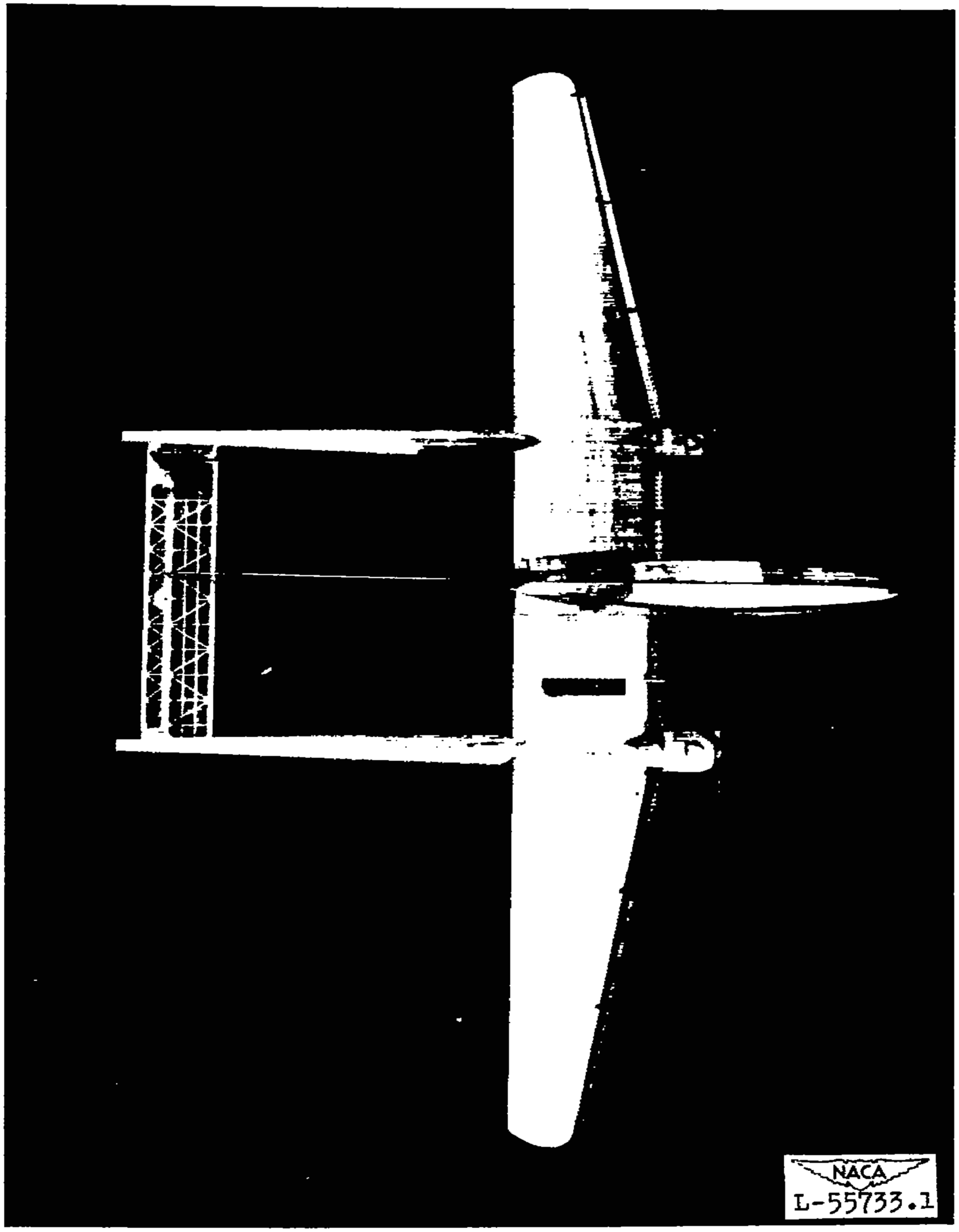

(b) Bottom view.

Figure 5.– Concluded.

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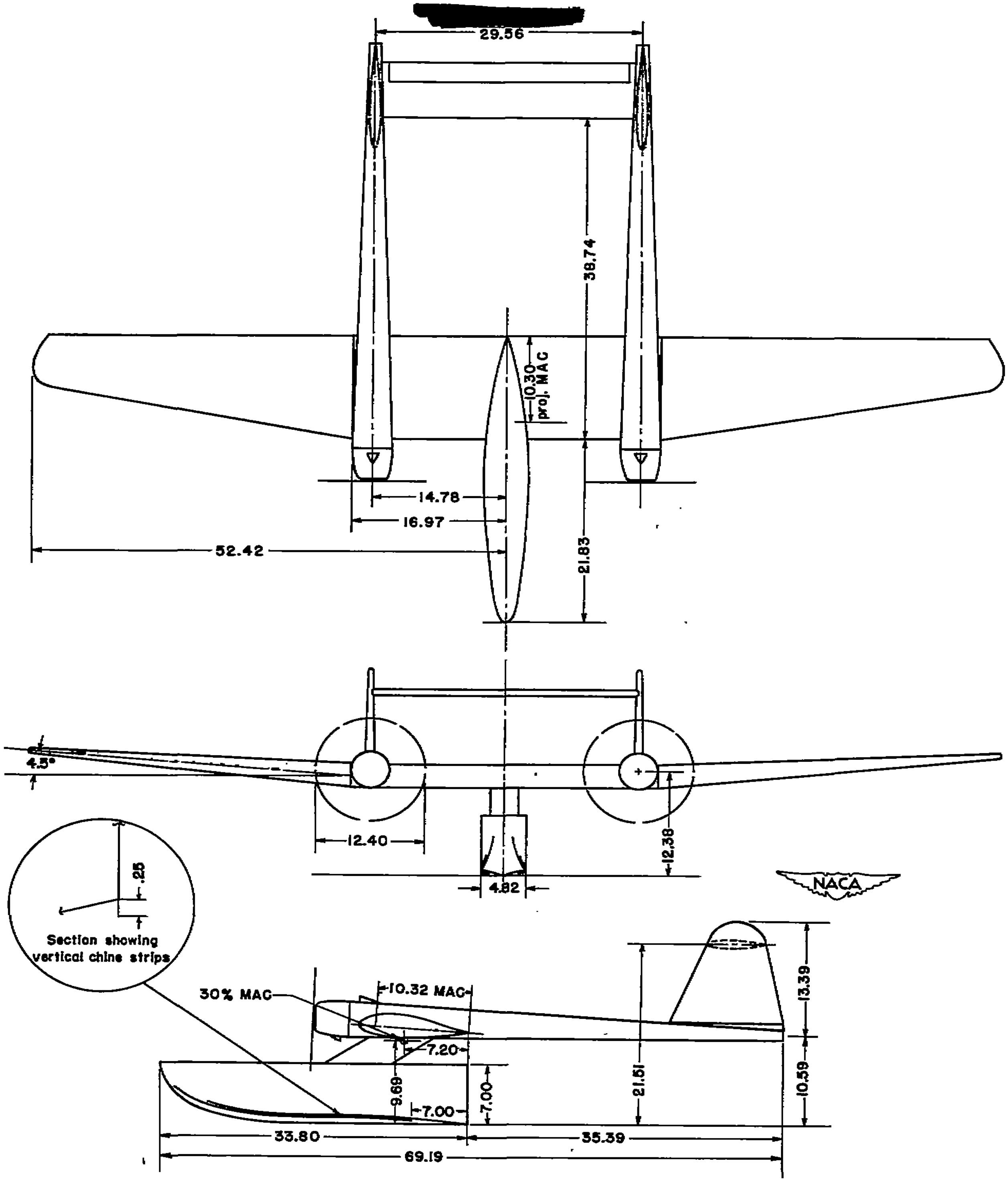

Figure 6.– General arrangement of model 237-7TB. (All dimensions are in inches.)

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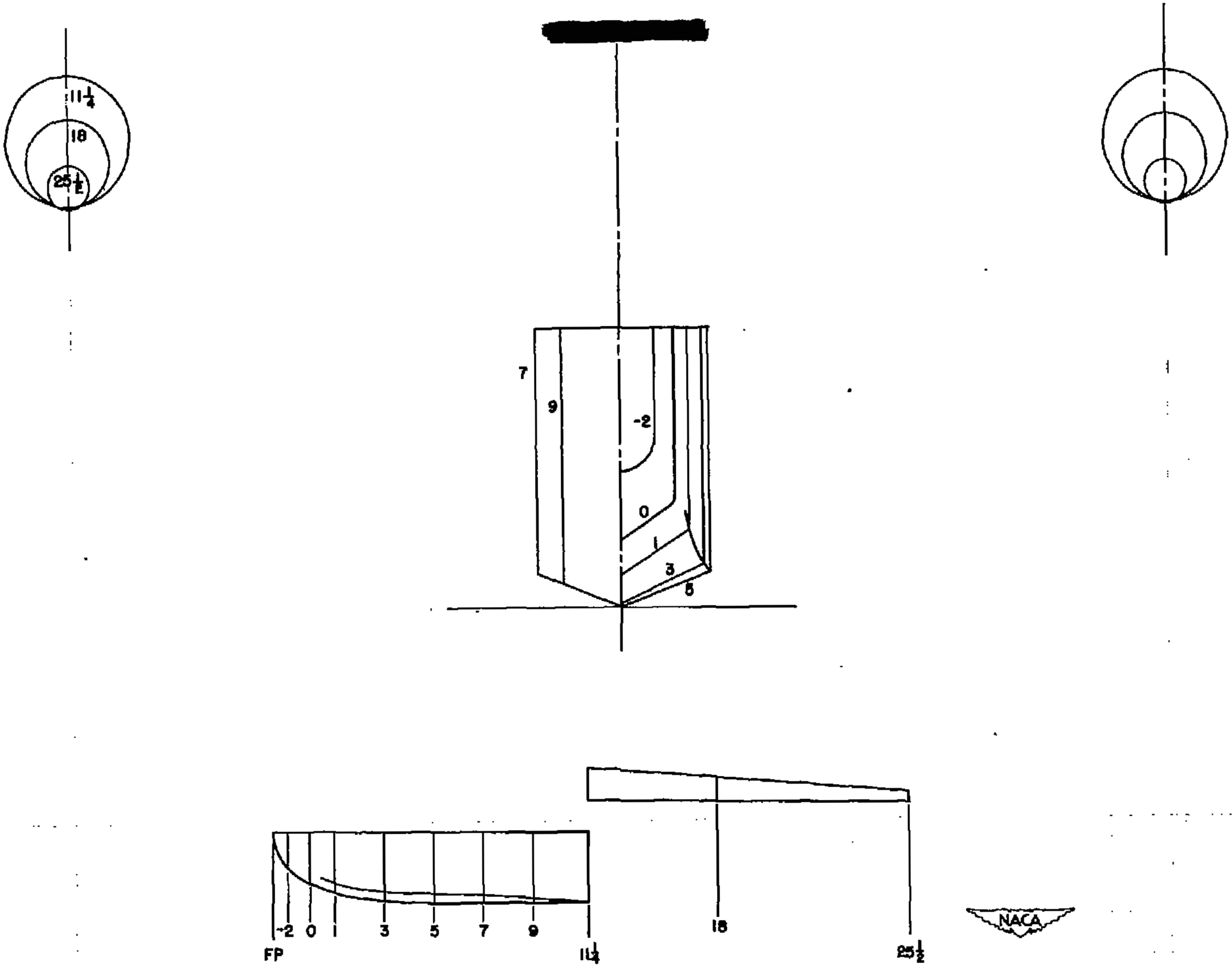

Figure 7.– Hull lines of model 237-7TB.

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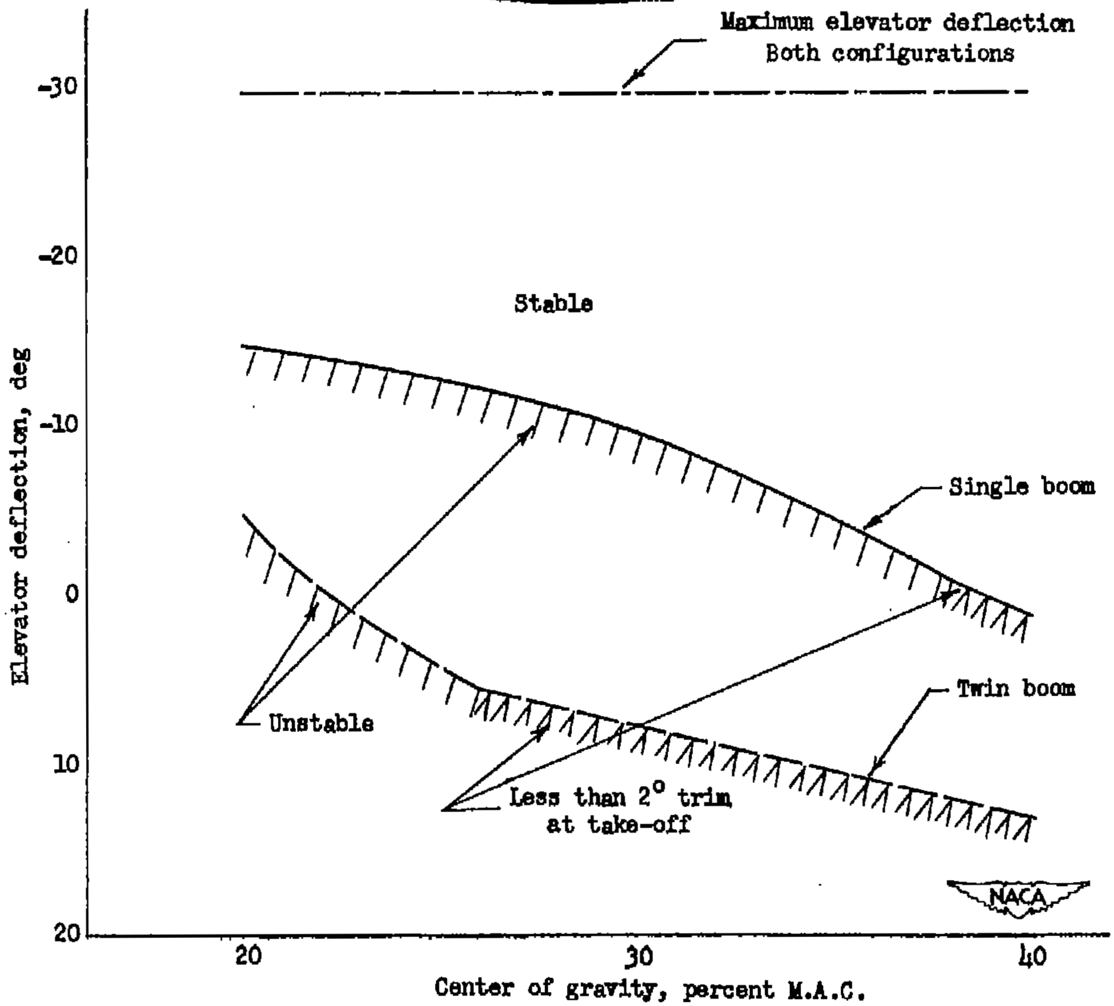

Figure 8.– Center-of-gravity limits of stability. Gross load coefficient 3.87; full power.

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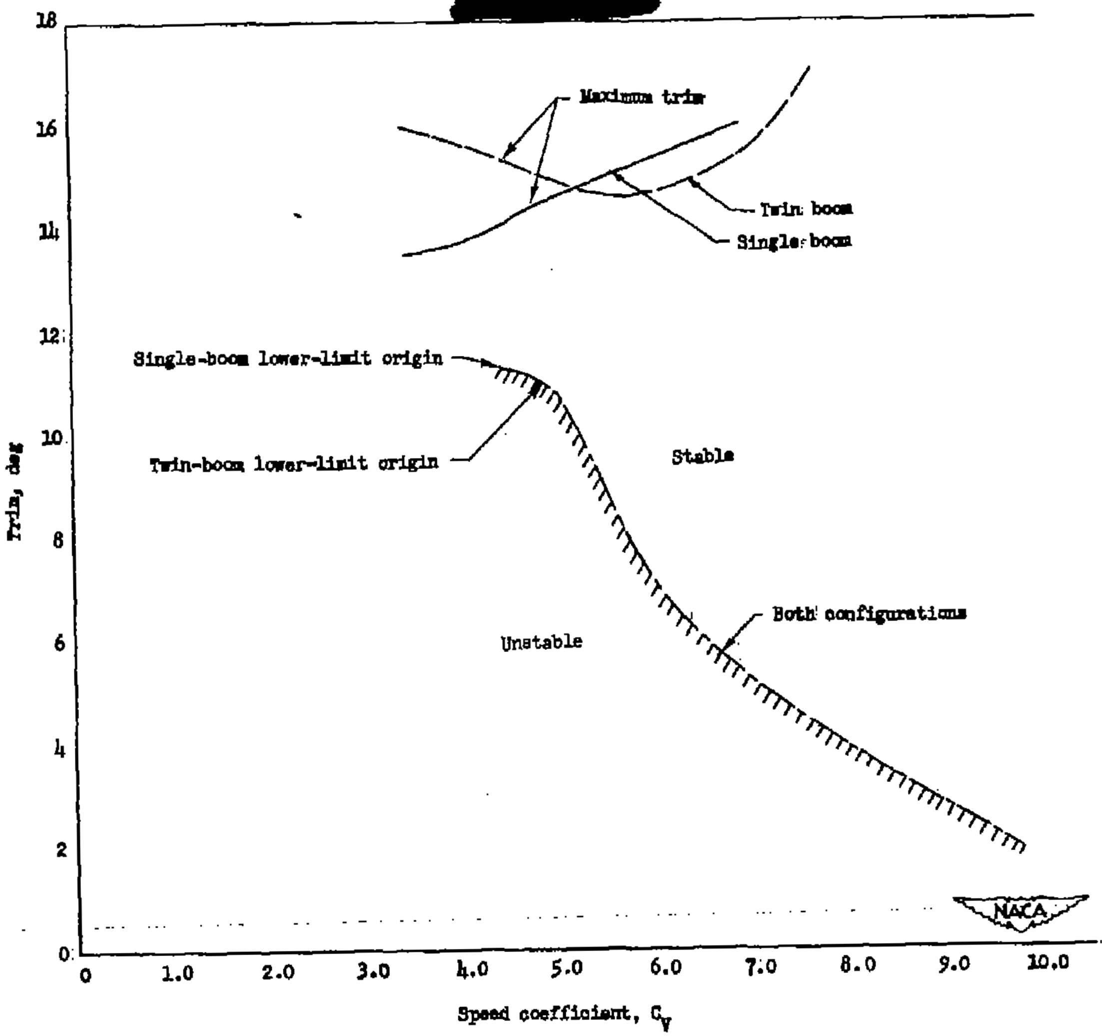

Figure 9.– Trim limits of stability.

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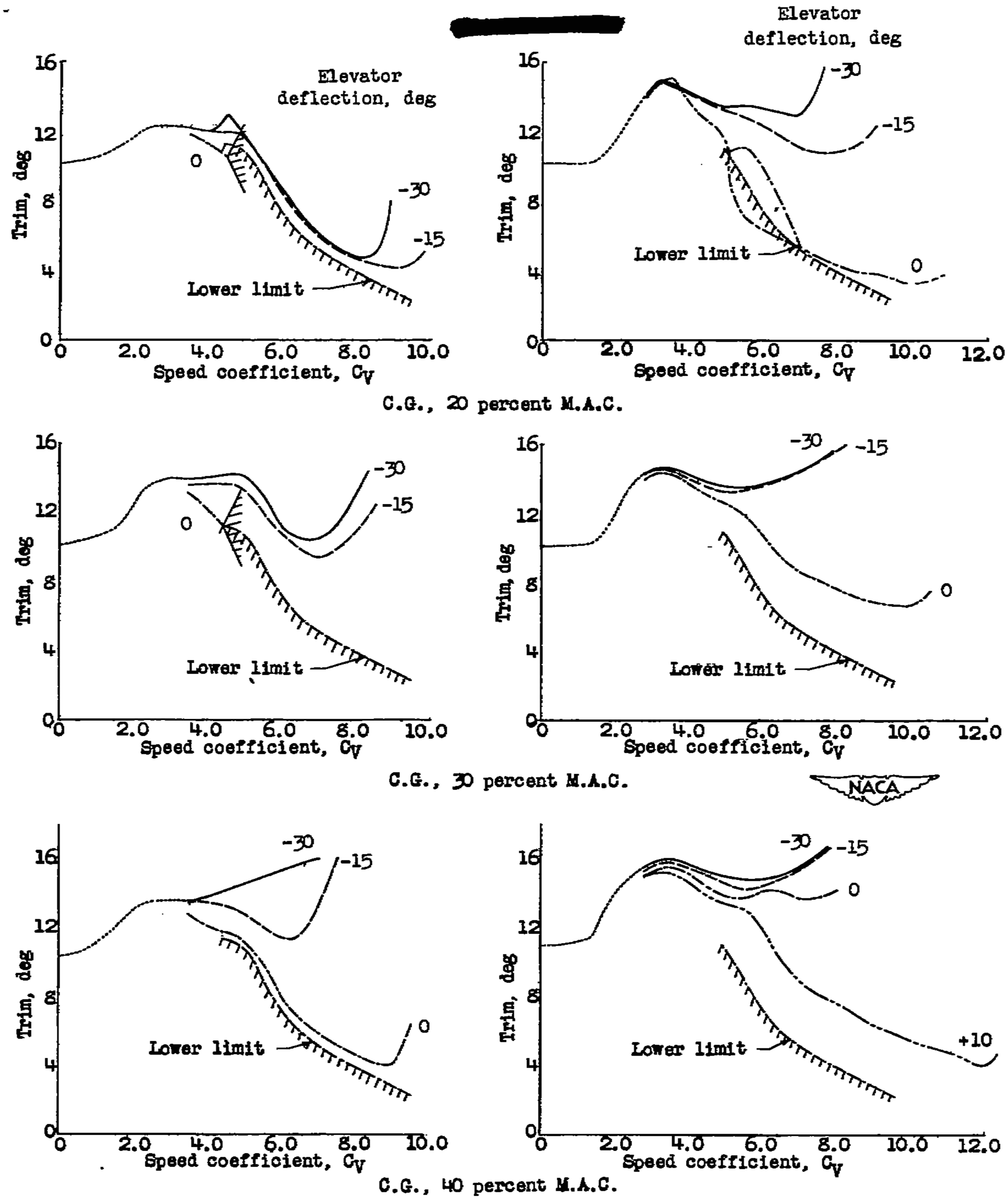

(a) Single boom. (b) Twin boom.

Figure 10.– Variation of trim with speed.

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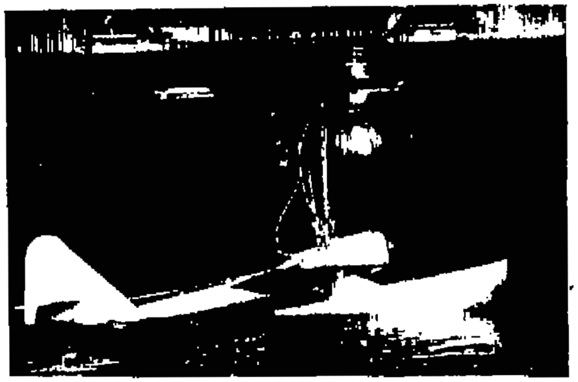
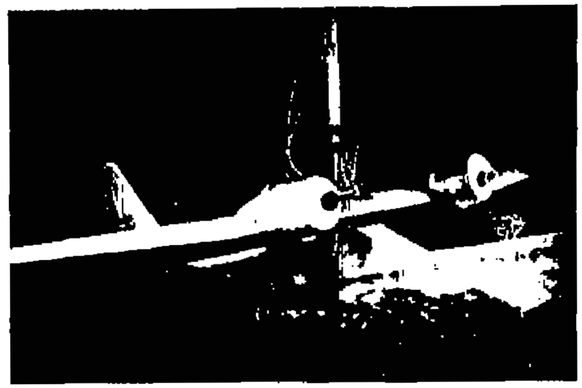
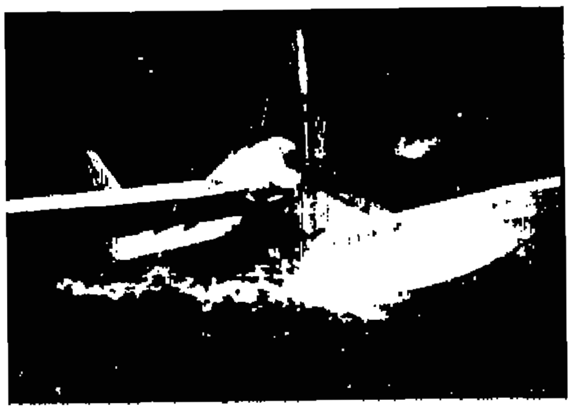


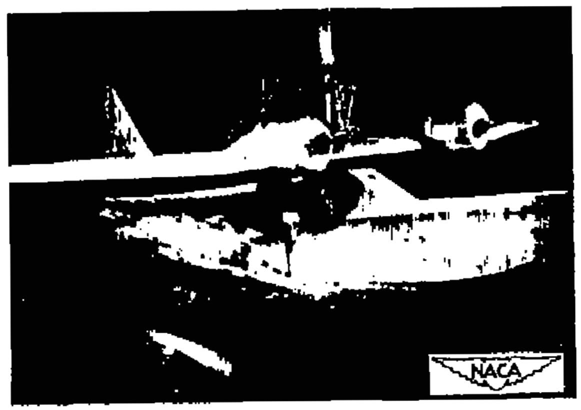
(a) $C_V = 0$; trim = 10.2°.



(b) $C_V = 1.94$; trim = 11.4°.



(c) $C_V = 3.62$; trim = 12.4°.



(d) $C_V = 8.35$; trim = 2.9°; (porpoising).

Figure 11.– Photographs of single-boom configuration being tested. Full power; gross load coefficient, 3.87.

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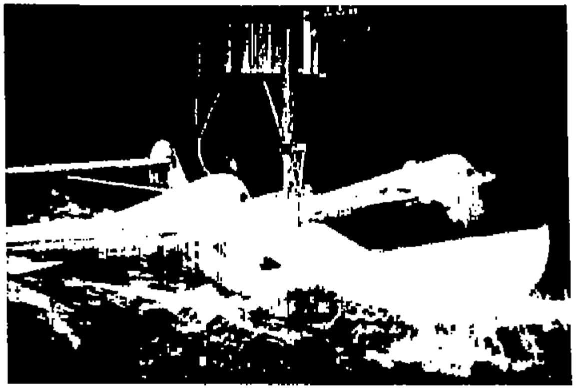
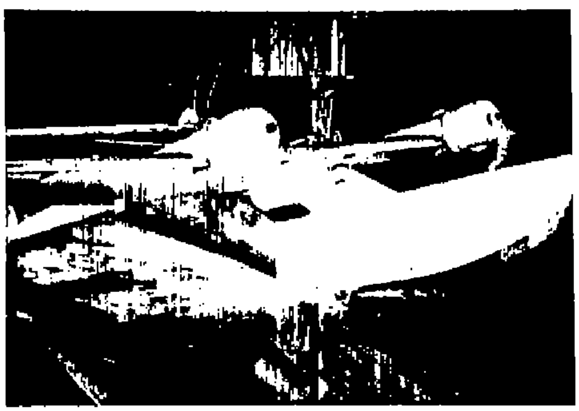
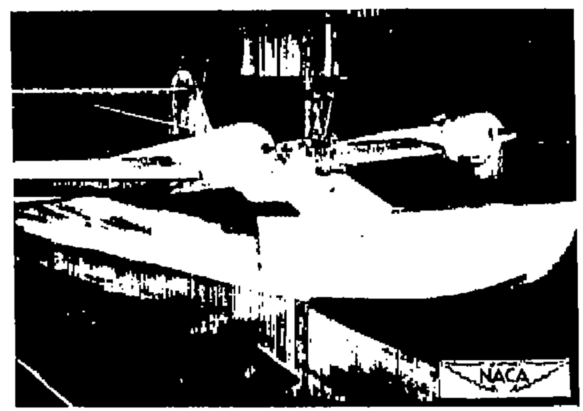


(a) $C_V = 2.12$; trim = 13.2°.

(b) $C_V = 2.92$; trim = 10.4°.



(c) $C_V = 6.26$; trim = 13.6°.



(d) $C_V = 8.35$; trim = 7.1°.

Figure 12.– Photographs of twin-boom configuration being tested. Full power; gross load coefficient, 3.87.

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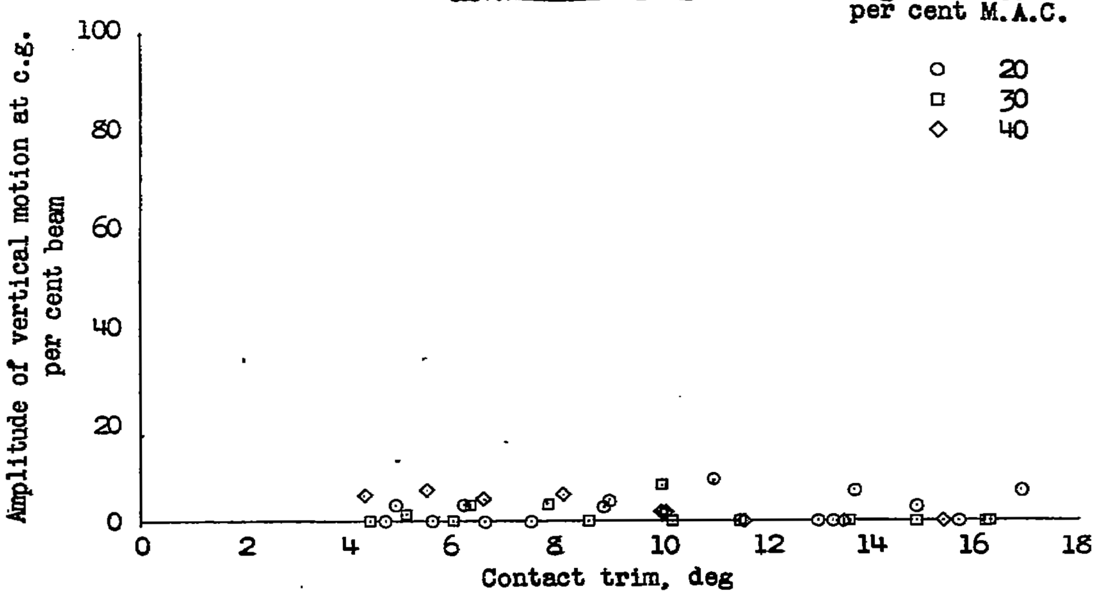
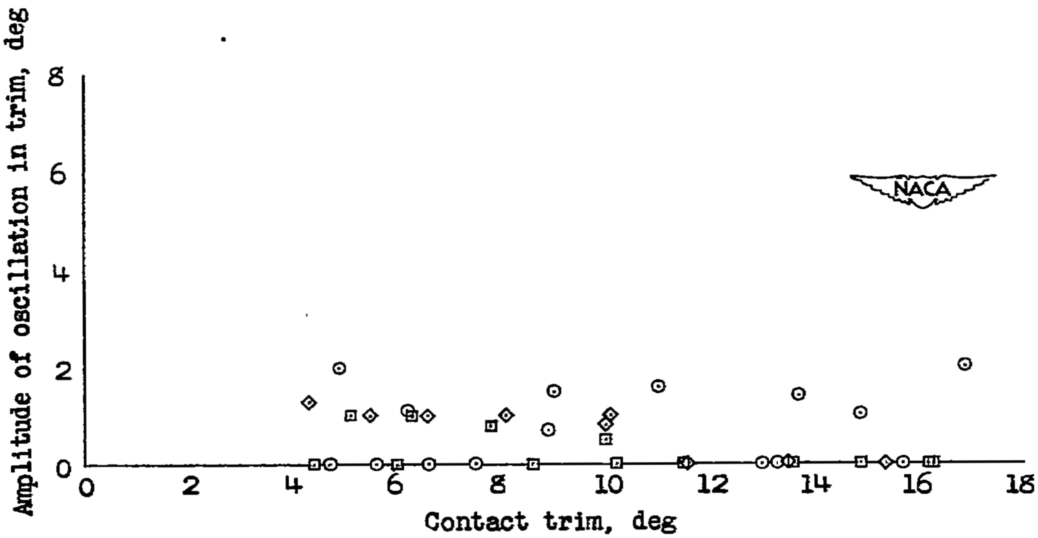


(a) Amplitude of vertical motion.



(b) Amplitude of trim oscillation.

Figure 13.– Landing stability of twin-boom model.

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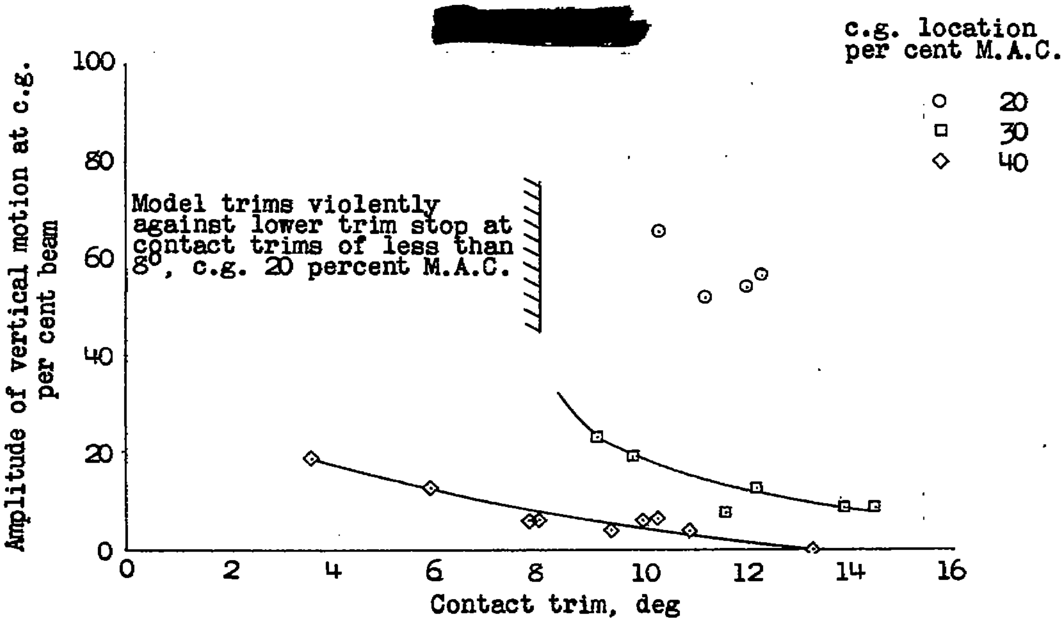
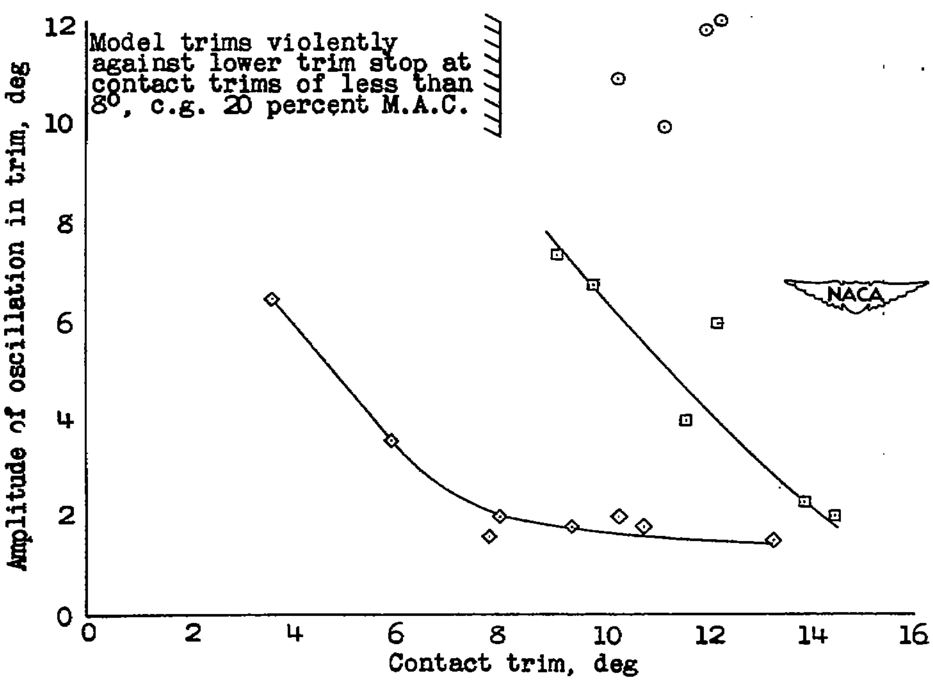


(a) Amplitude of vertical motion.



(b) Amplitude of trim oscillation.

Figure 14.– Landing stability of single-boom model.

[redacted]

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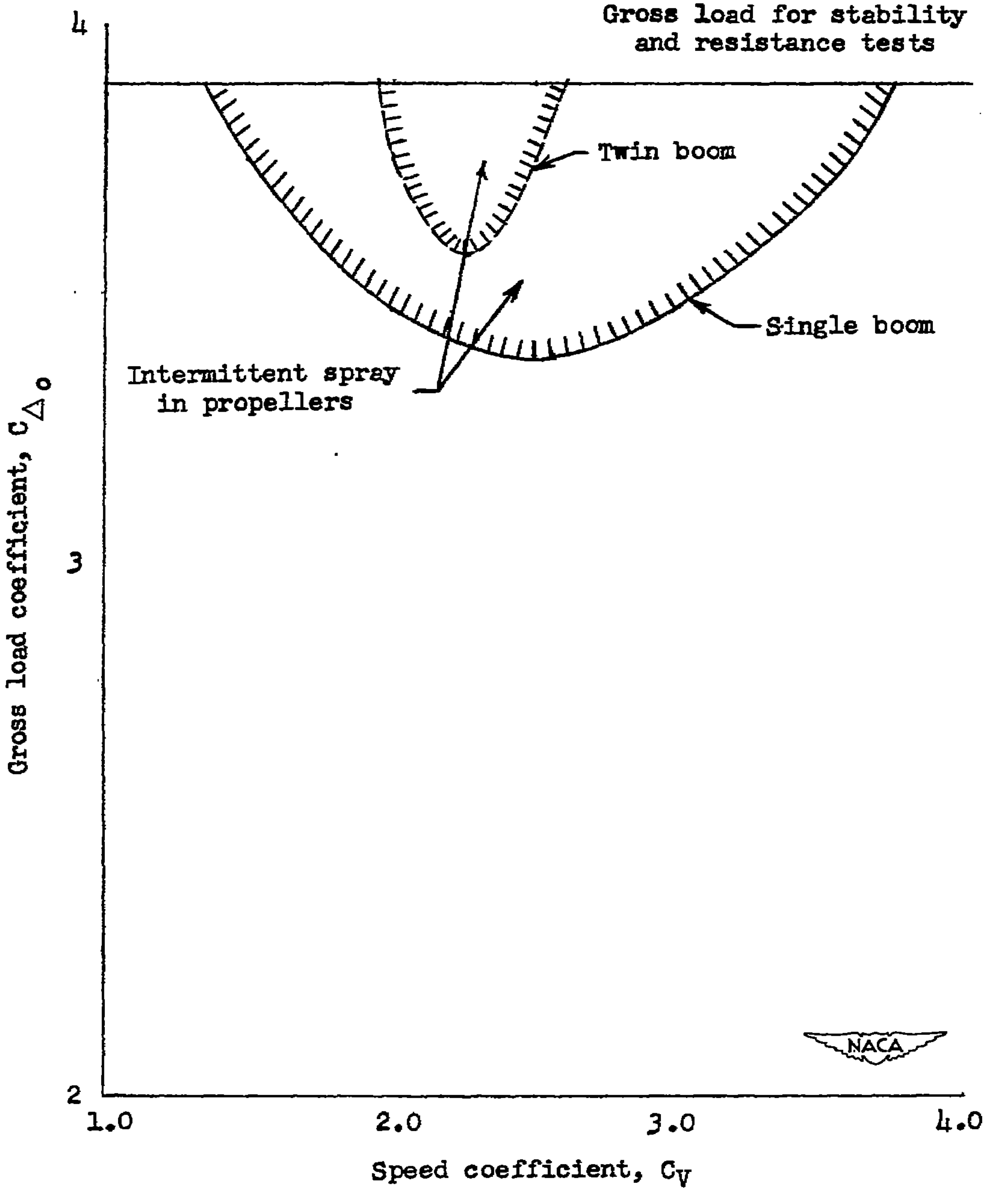

Figure 15.– Gross load coefficient at which spray enters propellers.

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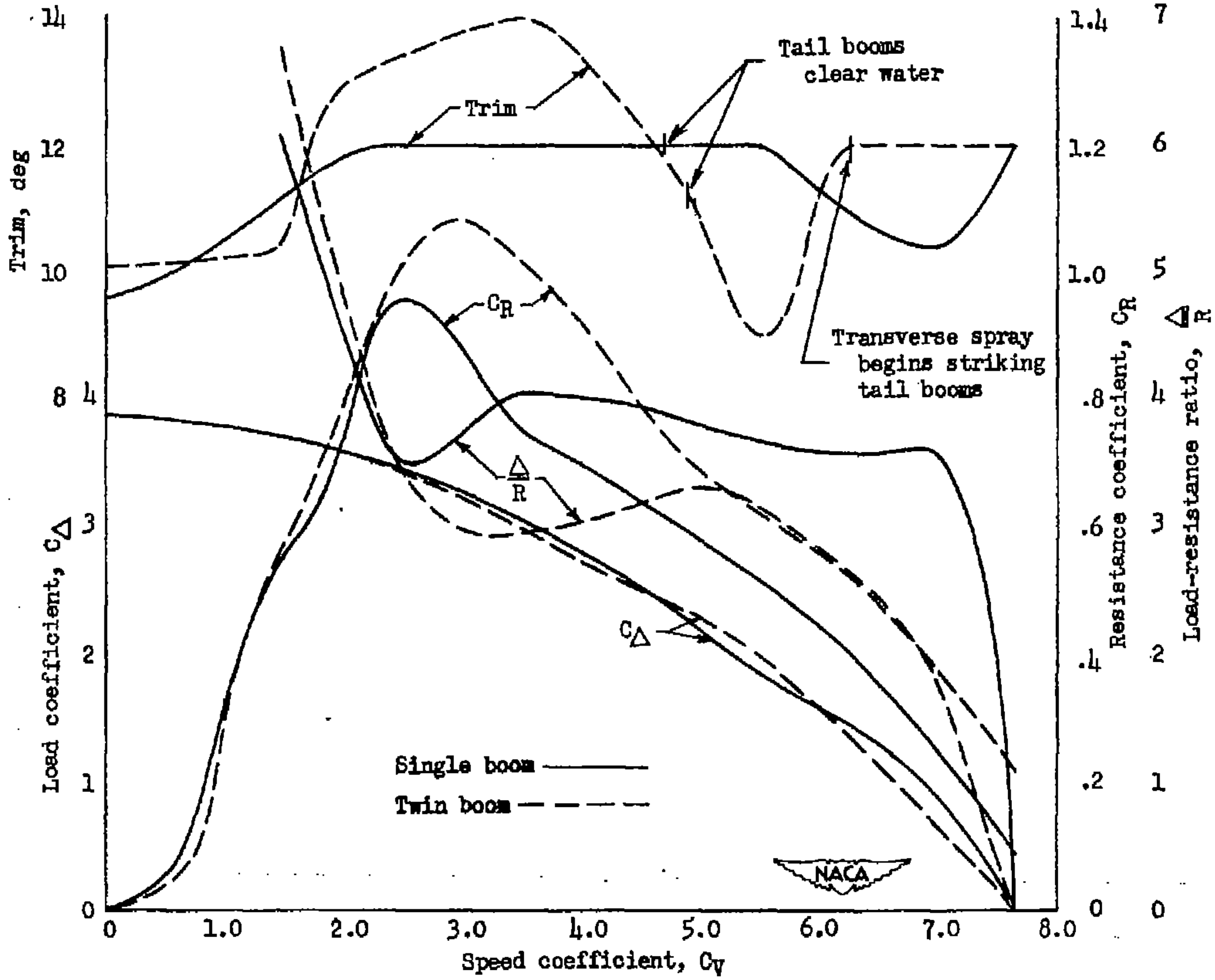

Figure 16.– Minimum stable resistance characteristics for single-boom and twin-boom hulls.

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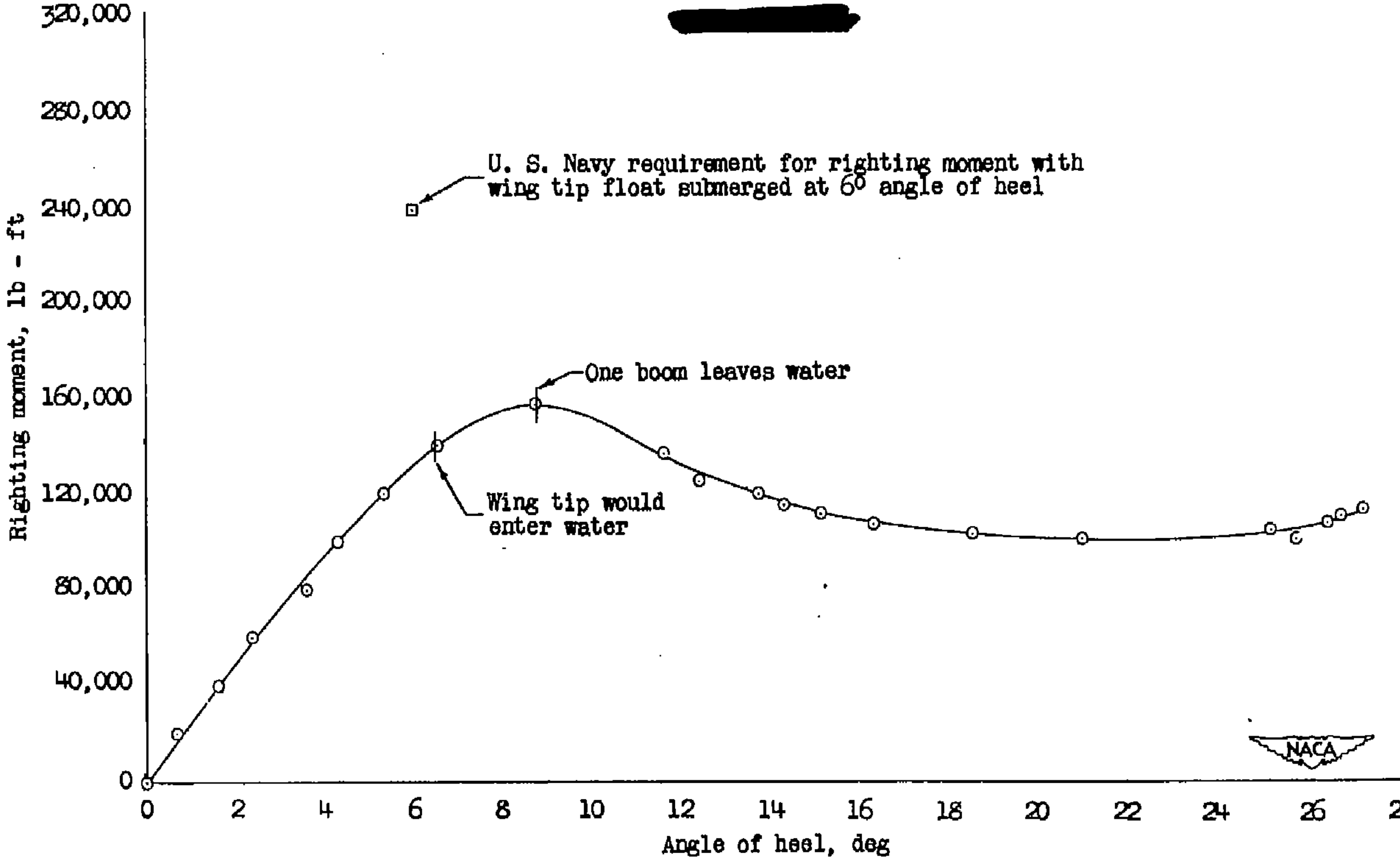

Figure 17.— Righting moment of twin-boom configuration without tip floats.

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